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HYDROLOGIC RELATIONS ON UNDISTURBED AND CONVERTED BIG SAGEBRUSH LANDS:

The Status of Our Knowledge

David L. Sturges

Abstract

The status of our knowledge of watershed management for big sagebrush range lands is discussed. Climate, soils, vegetation, snow accumulation, and water yields are described, followed by a review and discussion of how management practices alter vegetative composition and the hydrologic regime. Potential hydrologic benefits from managing blowing snow in the big sagebrush type are outlined and research needs are highlighted.

Keywords: Multiple use, range hydrology, vegetation effects, watershed management, blowing snow management, *Artemisia tridentata*.

PREFACE

Information about the hydrology of big sagebrush rangelands is scattered through the literature and is often contradictory. This Paper reviews published research, outlines important hydrologic features of big sagebrush lands, and describes how management practices alter the hydrologic regime. It represents the author's personal assessment of available research results and as such, is not intended to be a complete literature review. Full responsibility is assumed by the author for the input and for any shortcomings that subsequently become evident with increased hydrologic understanding.

The purpose of the Paper is to guide professional hydrologists and land managers by providing information on (1) what is known about the hydrology of big sagebrush lands, and (2) how this knowledge can be effectively used in reaching management decisions. This purpose will be well served should it stimulate critical thinking and additional hydrologic research.

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[1]*Central headquarters is maintained at Fort Collins, in cooperation with Colorado State University; research reported here was conducted at the Station's Research Work Unit at Laramie, in cooperation with the University of Wyoming. Portions of the research were supported by the Bureau of Land Management, U.S. Department of the Interior.*

Contents

HYDROLOGIC RELATIONS ON UNDISTURBED AND CONVERTED BIG SAGEBRUSH LANDS: The Status of Our Knowledge

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THE BIG SAGEBRUSH TYPE

The Physical Setting

Shrub members of the genus *Artemisia* L. occupy lands extending from southern Canada to northern Mexico, and from the edge of the Great Plains west to the Pacific Ocean in southern California. Their range in the 11 western States encompasses about 270 million acres. One *Artemisia*, big sagebrush *(A. tridentata)*, accounts for 196 million acres of the total acreage. The big sagebrush type embraces a wide range of environmental characteristics, extending as it does over much of western North America. However, certain hydrologic features are common throughout the type which permit a meaningful hydrologic discussion (fig. 1).

A

B

Figure 1.—Three subspecies comprise the big sagebrush complex:

A, Basin big sagebrush is an erect shrub 1-2 meters tall and usually grows below 5,000 ft;

B, Mountain big sagebrush is a flat-topped shrub up to 1 meter tall and commonly grows above 7,000 ft;

C, Wyoming big sagebrush is a dwarf shrub, often suggestive of black sagebrush (*A. nova*), and grows on shallow soils between 5,000 and 7,000 ft.

Although this Paper is restricted to a hydrologic discussion of big sagebrush, the explored relationships have broader applicability since many of the *Artemisias* are closely related to big sagebrush in growth form and habitat requirements.

Big sagebrush lands are semiarid, receiving about 8 to 20 inches of precipitation annually. One-half to two-thirds of yearly precipitation falls during winter, mostly as snow. The relocation of snow by winter winds and attendant water loss by sublimation during transport are important hydrologic features. Snow accumulates through the winter but melts rapidly as temperatures warm in the spring. The water then becomes available for onsite use, for export from the melt site as overland flow, or, in the higher precipitation zones, may enter a groundwater system and support perennial streamflow.

Vegetative growth depends on melt water stored in the soil. Summers are typically warm, the evaporation rate is high, and summer rainfall is ineffectual in replenishing soil moisture. Some sagebrush lands are subject to convectional summer storms that may produce high runoff rates and erosion.

The Individual Plant

Big sagebrush (fig. 1) is a species with enormous genetic plasticity. Three subspecies—basin *(A. tridentata tridentata),* Wyoming *(A. t. wyomingensis),* and mountain *(A. t. vaseyana)*—are recognized by Beetle (1960) and Beetle and Young (1967). Positive identification of species and subspecies, where appropriate, is important because plants are often indicative of important environmental differences. Mountain big sagebrush, for example, typically grows above 7,000 feet on lands receiving a large proportion of yearly precipitation as snow that is subsequently drifted by wind. Consequently, areas supporting this subspecies present a greater opportunity for water management than does Wyoming big sagebrush, which grows below 5,000 feet on sites with less soil development and lower precipitation.

The advent of thin-layer chromatography offers a means to identify sagebrush species and to separate subspecies independent of traditional taxonomic keys. Such identification in the past would have prevented many of the contradictions that presently abound in big sagebrush literature. Brunner (1972) describes how the technique can be used on a practical basis to identify sagebrush species as well as subspecies within the big sagebrush complex. Paper and thin-layer chromatography of big sagebrush seeds also provide the means of separating basin big sagebrush seeds from those of Wyoming or mountain big sagebrush (Hanks and Jorgensen 1973). The technique also provides a quantitative means of identifying individual big sagebrush plants palatable to livestock and big game (Hanks and others 1971).

Big sagebrush is particularly adapted to an environment with a warm and dry growing season, where vegetation exists primarily on moisture stored in the soil at the time of snowmelt. Diettert (1938) believes the presence of trichomes or hairs, which produce the silvery gray appearance of foliage, may be one of sagebrush's primary adaptations in limiting moisture loss from leaves. The numerous trichomes, present on both sides of a leaf, form a dense, hairy covering about 200 micrometers thick. The closing of leaf stomates also helps to maintain a favorable internal water balance as soil moisture becomes limiting.

Sagebrush responds to dry conditions by reducing the size of leaves. Plants growing on sites with less favorable moisture relations have smaller leaves than plants where moisture is sufficient. Leaves produced late in summer are considerably smaller than those produced earlier in the season when moisture was readily available. Big sagebrush has a pronounced leaf drop in midsummer, although some leaves are shed throughout the year (Diettert 1938). The rate of photosynthesis declines sharply at the time of midsummer leaf drop which De Puit and Caldwell (1973) attribute primarily to the closing of stomates caused by high internal water stress. However, phenological factors within the plant may also play a role in limiting photosynthesis and water loss as the growing season advances.

The root system of big sagebrush enables it to compete efficiently for moisture and nutrients. The majority of roots are located in the upper 2 feet of soil; a particularly dense network of interwoven roots develop beneath the crown in the surface 6 inches of soil. Plants either have a taproot or several dominant lateral roots commonly extending 5 to 6 feet deep. Much deeper roots have been observed on alluvial soils. The dense network of shallow roots competes directly with associated herbaceous species for moisture, usually the factor most limiting growth in the sagebrush environment. The deeper roots permit sagebrush to tap moisture reserves unavailable to herbaceous species and to remain physiologically active through the summer drought period. Deep roots also provide a definite competitive advantage in surviving prolonged climatic droughts.

Management of Big Sagebrush Lands

Grazing by domestic livestock (fig. 2) has been and will remain the dominant usage by man on most sagebrush lands, despite a burgeoning population and expanding recreational pressure. Although wildlife habitat, recreation, and mining are also important uses of the type, only livestock use is discussed here since past management practices on sagebrush lands affecting their hydrologic performance were done in a livestock context.

Big sagebrush is the most productive element of its ecosystem, but herbage has a low value for livestock forage except to sheep on winter range. Overgrazing the herbaceous species which comprise the forage resource in the type can reduce their competitiveness to such an extent that sagebrush completely dominates the site. The dense stands of brush persist for decades, since individual big sagebrush plants commonly live 50 to 75 years. Sagebrush conversion is one of the chief tools utilized by range managers to restore grazing productivity. After the brush is removed, sites are either reseeded, or allowed to return to native herbaceous vegetation if density of desirable plants is sufficient to quickly occupy the site.

Because economic returns from livestock grazing are low, sagebrush removal methods must be inexpensive. Burning, an early means of conversion, still remains a viable technique. Mechanical procedures came into widespread use with development of large crawler tractors, but they are limited to slightly rocky sites of moderate slope. Discovery of 2,4-D, one of the phenoxy herbicides, revolutionized management of big sagebrush lands. Spraying was adopted as the preferred method of sagebrush control[2] in the late 1950's. The practice was readily accepted by managers of both privately and publicly owned lands. Figures for sagebrush control acreages in Wyoming illustrate trends throughout the West. In the 10-year period from 1952-62, about 16,000 acres of sagebrush land were mechanically controlled but 319,000 acres were sprayed. Between 1963 and 1970, however, sprayed acreage in Wyoming increased to 1.3 to 1.4 million acres.[3]

Figure 2.—Big sagebrush rangelands are an important grazing resource for both cattle and sheep. Historically, these lands linked the vast desert ranges and the mountain summer ranges.

HYDROLOGIC FEATURES OF MOUNTAIN BIG SAGEBRUSH

Many phases of the hydrologic cycle for big sagebrush are poorly understood. The type has received little attention because watershed management research efforts have been concentrated in regions of greater precipitation. However, big sagebrush lands, particularly those vegetated by mountain sagebrush, include areas of heavy snow accumulation that support perennial streamflow. The features discussed here are not all inclusive, but were selected as especially important characteristics that shape the hydrology of mountain sagebrush lands.

Specific data contained in the text and figures of this report, unless otherwise noted, come from two Wyoming sites where big sagebrush hydrologic studies have been conducted by the Rocky Mountain Forest and Range Experiment Station. Wayne's Creek, located in the northwest part of the State at an altitude of 9,500 feet, is representative of conditions on high-elevation, mountain big sagebrush lands. The Stratton Sagebrush Hydrology Study Area, situated in south-central Wyoming at 7,800 feet, was established in cooperation with the Bureau of Land Management. Dense stands of mountain big sagebrush are present on mesic sites at Stratton, and Wyoming big sagebrush and black sage *(A. nova)* are found on the drier upland slopes and the ridges. Mountain sagebrush stands at both study locations are thrifty

[2]2, 4-D is currently registered for control of big sagebrush. Since pesticide registrations are under constant review, use of any pesticide should be checked with appropriate State or Federal agencies.

[3]Unpublished material from W. G. Kearl, Agricultural Economist, University of Wyoming, Laramie.

and underlain by productive soils. Such areas are typical of those where sagebrush has been controlled as a range improvement practice. This type of land is also the source of perennial streamflow.

Precipitation

Stands of big sagebrush indicate a climate with a relatively warm and dry growing season, where the bulk of yearly precipitation is received during the cold months. Mountain big sagebrush receives 15 to 20 inches of precipitation per year, about 60 percent of the total as snow (fig. 3). Temperatures are sufficiently low to prevent melting throughout the winter in the higher parts of the mountain sagebrush zone, but some melting does occur at lower elevations. The transition to a summer precipitation regime begins in April or May when precipitation may fall as snow, rain, or a rain-snow mixture. By September, reversion to winter conditions has begun. Precipitation received after October falls as snow, and by November temperatures are sufficiently cold to hold the snow until melt begins in April or May. Snow that falls in the spring and early fall usually melts within a few days.

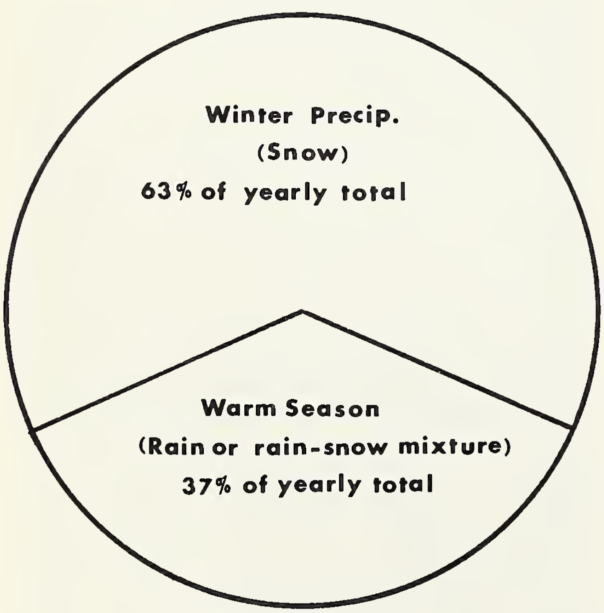

Figure 3.—The majority of yearly precipitation in the mountain sagebrush zone falls during the winter as snow.

Summer precipitation is concentrated in the months of June and September, when more than 60 percent of the warm-season total is received (fig. 4). June rainfall is important for plant growth, but that received during July, August, and September is of little consequence. September rainfall does replenish soil moisture, thus reducing the quantity of snowmelt water required for soil recharge in the spring. The distribution of summer rainfall by 0.10-inch precipitation classes (fig. 5) emphasizes the small size of most events. For example, 0.10 inch or less fell on about two-thirds of the days with precipitation. Precipitation exceeded 0.50 inch on just 6 percent of the days that rain fell.

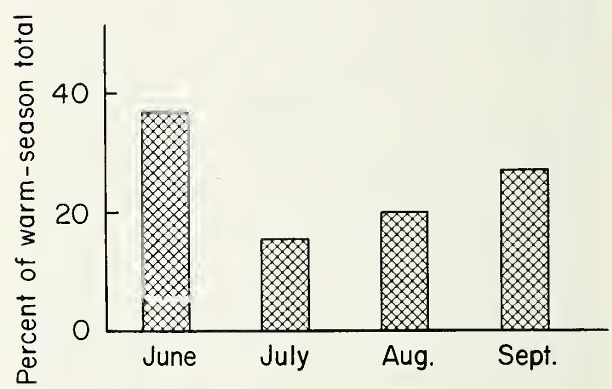

Figure 4.—About 60 percent of the warm-season precipitation is received in June and September in the mountain sagebrush zone.

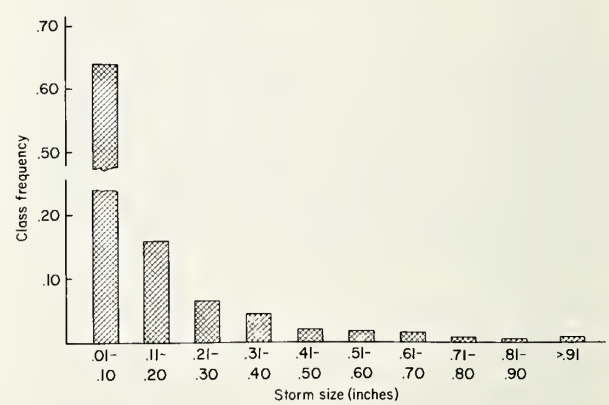

Figure 5.—The majority of summer precipitation events are small in the mountain sagebrush zone; daily precipitation is less than 0.21 inch on about 80 percent of days with precipitation.

Rainfall intensities greater than 1 inch per hour generally last less than 10 minutes. Average intensity for entire storm periods is usually below 1 inch per hour, considerably less intense than the period of maximum rainfall within a storm (table 1).

Table 1.--Precipitation characteristics for summer storms with rainfall bursts that exceeded 1.00 inch per hour (in/h) intensity at two hydrologic study sites in Wyoming

Characteristics	Stratton	Wayne's Creek
Years of record (number)	5	8
Minimum storm size (inch)	>0.25	>0.50
Events (number)	7	4
Total storm--		
Intensity of		
<1 in/h	6	3
>1 in/h	1	1
Duration of		
<30 min	4	1
30-60 min	0	0
>60 min	3	3
Maximum rainfall burst--		
Intensity of		
1-2 in/h	4	3
2-3 in/h	2	0
>3 in/h	1	1
Duration of		
<10 min	7	3
>10 min	0	1

Wind and Drifting Snow

Wind is an extremely important part of the physical environment on mountain sagebrush lands because of its role in snow transport. Speeds reach a maximum during the winter months, thus accentuating the blowing snow phenomenon, one of the distinctive features of sagebrush hydrology (figs. 6 and 7). Much of

Figure 6.—Blowing snow is a distinctive hydrologic feature of mountain sagebrush lands; a substantial portion of winter precipitation can return to the atmosphere during drifting.

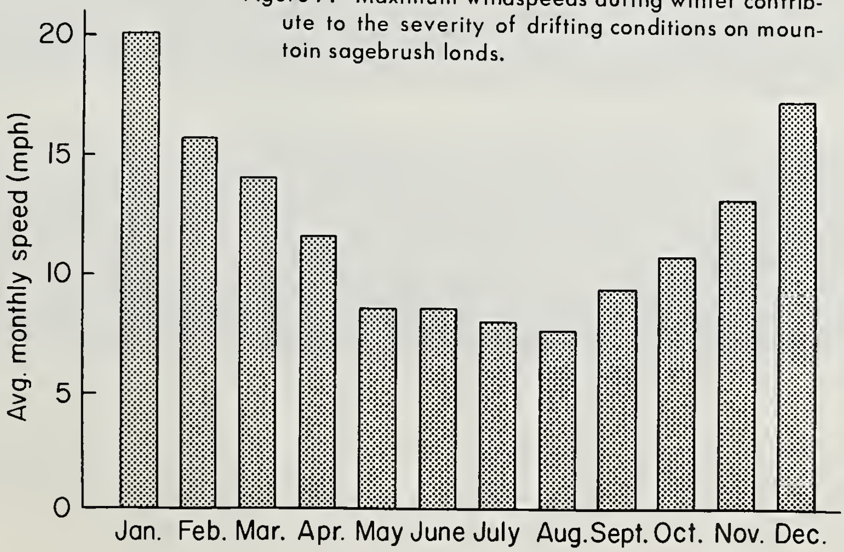

Figure 7.—Maximum windspeeds during winter contribute to the severity of drifting conditions on mountain sagebrush lands.

the snow that falls on higher elevation lands is blown from windward slopes and ridge areas to topographically controlled depositional sites such as the lee side of ridges or incised drainages. Newly fallen snow begins to drift when winds reach about 12 miles per hour; greater speeds are required for transport of metamorphosed snow.

An unknown proportion of winter precipitation is returned to the atmosphere during drifting. Schmidt (1972) formulated a mathematical model that describes the sublimation process in terms of relative effects of various environmental parameters on the sublimation rate. Calculations suggest that large quantities of water return to the atmosphere during a drifting event. Field measurements by Tabler (1972) in southeast Wyoming also indicate that a substantial portion of winter precipitation does return to the atmosphere. The average distance required for a drifting snow particle to sublimate (transport distance) was about two-thirds of a mile. Based on this figure, (Tabler (1973) subsequently showed that, when major natural traps which accumulate drifting snow are spaced at distances of 0.5, 1,0, and 2.0, and 3.0 times the average transport distance, 25, 50, and 75, and 83 percent, respectively, of the drifting snow returns to the atmosphere.

Snow commonly accumulates in drifts 10 to 20 feet deep where drifting conditions are severe. The larger drifts contain more water than required to satisfy the soil-moisture deficit, and the excess may be yielded to ground water. The concentration of snow by wind and subsequent ground-water recharge is probably responsible for the presence of springs and perennial streamflow from sagebrush lands. The large drifts persist into June, long after the general snowpack has melted (fig. 8). By this time, daytime temperatures reach 60° to 70°F and incoming solar radiation is near the yearly maximum. The magnitude of evaporation from the snow and moistened soil is unknown, but it could account for a substantial part of drift-water volume. This aspect of sagebrush hydrology needs investigation. Evaporation losses from isolated drifts behind 4-foot-high snowfences equaled about half of the water content of the drift (Saulmon 1973), but it is not known if losses of this magnitude are representative for large drifts.

Infiltration and Sediment Transport

The factors governing infiltration and sediment movement are complex, and their interrelationships poorly understood. Investigators have relied on multiple regression analysis to identify soil, cover, and topographic parameters that relate to infiltration and erosion. These studies were conducted on small plots with

Figure 8.—Deep snowdrifts thot persist long after generol watershed snow cover has melted recharge ground water:
A, Snow conditions on June 3, neor the time of peok snowmelt runoff;
B, Snow conditions on June 16, obout 1 week after the hydrogroph peok.

artificially applied rainfall. To date, it has not been possible to develop specific relationships that are generally applicable over widespread areas.

There is agreement that watershed cover, variously defined but often including litter and rock besides basal and canopy coverage of live vegetation, is an important factor influencing infiltration and erosion caused by overland flow. Soil protection must increase as slope angle increases since the erosive power of water is closely related to flow velocity. The size of particles that water can transport increases approximately as the fifth power of velocity, while the quantity of sediment water can transport varies from the 3.2 to 4.0 power of velocity (Twenhofel 1950).

The ability to predict infiltration is further compounded by the changing importance of factors that govern infiltration with time. An empirical relationship may be valid at one time of the year but in appreciable error 3 months later (Gifford 1972). Infiltration rates are characteristically higher in the spring because of increased soil porosity caused by freezing and thawing overwinter, but then decrease as the season advances. Grazing, by removing plant material and compacting the soil, reduces infiltration rates within a season (Gifford and Busby 1974). Soil texture and organic matter content are other important soil factors that influence infiltration and sedimentation. The relationship between organic matter content of soil and soil erodibility indicates the complexity of infiltration and erosion processes. Organic matter decreases erosion of clay soils but increases erosion of sandy soils (Meeuwig 1971).

Infiltration measurements at many locations in the sagebrush type indicate that steady-state infiltration usually exceeds 1 inch per hour, and often exceeds 2 inches per hour during the first 10 minutes of rain. The land manager influences the amount of bare soil, litter, and vegetation through management decisions. Practices that increase the amount of watershed cover at the expense of bare soil promote soil stability.

Soil has no single infiltration capacity; rather, the infiltration rate is related to moisture content. The rate decreases markedly as dry soil is moistened during the first 15 minutes of rain, but then decreases at a much slower rate as additional time passes, or it may become constant (Gifford 1968). The initial infiltration rate of premoistened soil is lower than that of dry soil. These relationships have important implications for field situations. Overland flow will be produced from rain falling at lower intensities when soil is moistened than if it were dry. Rain falling at a constant intensity on dry soil may be absorbed for a period of time, but then as the infiltration rate falls below rainfall intensity, overland flow can start.

Water Yield Characteristics

Sagebrush and Timbered Lands Contrasted

Streamflow characteristics of sagebrush lands can be appreciated by comparing flow regimes with those of a timbered subalpine watershed. Figure 9 compares yearly hydrograph of Loco Creek on the Stratton Experimental Area with Fool Creek on the Fraser Experimental Forest near Fraser, Colorado. The hydrograph of Fool Creek is a composite developed from 15 years of record prior to timber harvest (Leaf 1975). Selected flow characteristics for the two watersheds are summarized in table 2.

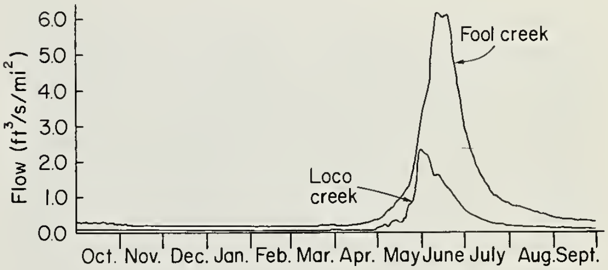

Figure 9.—Base flow, peak flow during snowmelt, and volume of snowmelt runoff are greater on forested subalpine watersheds (Fool Creek) than on sagebrush watersheds (Loco Creek).

Gross differences between the hydrographs are readily apparent. Base flow on the timbered watershed is more than twice as great as from Loco Creek, and peak flow rates during snowmelt are almost three times as great. Fool Creek yields 42 percent of annual precipitation as runoff, while the yield on Loco Creek is 22 percent. Snowmelt runoff persists longer on the forest watershed. The timing of snowmelt, and snowmelt discharge rates, probably vary more in the sagebrush type than on timbered land. Snowmelt is responsive to warm temperatures in the late winter and early spring because sagebrush lands are at a lower elevation, the snowpack is shallower, and snow is directly exposed to solar radiation. Advected energy is

Table 2.--Selected flow characteristics for a timbered subalpine watershed (Fool Creek, Fraser Experimental Forest, Colorado) and a sagebrush watershed (Loco Creek, Stratton Experimental Area, Wyoming)

Parameter	Fool Creek (1940-55)	Loco Creek (1968)
Area (acres)	714	1,639
Average annual precipitation (inches)	26.1	15.2
Runoff (area-inches)	11.1	3.3
Yield efficiency (percent)	42	22
Peak daily discharge ($ft^3/s/mi^2$)	6.1	2.3
Duration snowmelt runoff (days)	134	118
Days to accumulate:		
First 25% of snowmelt runoff	50	33
Second 25% " " " "	9	9
Third 25% " " " "	11	11
Fourth 25% " " " "	64	65

probably an important energy source driving melt on sagebrush lands, but is of lesser importance in the forest environment.

The form of the snowmelt hydrograph is similar for Loco Creek and Fool Creek even though runoff volume, flow rate, and runoff duration were greater for the timbered watershed. For example, the time required to accumulate the first 25 percent of snowmelt runoff equaled 37 percent of the melt season on Fool Creek and 28 percent of the season on Loco Creek. The next 50 percent of runoff volume was produced during a brief interval that comprised just 15 percent of the runoff period for both the forested and sagebrush watersheds. This flow volume equaled about 35 percent of total annual flow on the two areas. The time required to accrue the last 25 percent of snowmelt runoff equaled 48 percent of the runoff interval for Fool Creek, and 55 percent of the runoff interval at Loco Creek.

Snowmelt Runoff in Mountain Big Sagebrush

Flow volumes during the snowmelt season are extremely sensitive to daily fluctuations in weather, as reflected by the erratic nature of daily discharge for Wayne's Creek (fig. 10). Maximum snowmelt discharge can vary from early to late in the melt season, depending on the availability of energy to drive the melt process and the quantity of snow remaining on the watershed. The depth of snow and watershed slope orientation are other important factors contributing to the variability of snowmelt runoff. The warmer south- and west-facing slopes promote faster melting than a north exposure where radiation influx is less. The volume of snowmelt runoff is also more responsive to short-term weather patterns on areas with a shallow snowpack than where snow is in deep drifts because of the energy difference required to warm snow to the melting point.

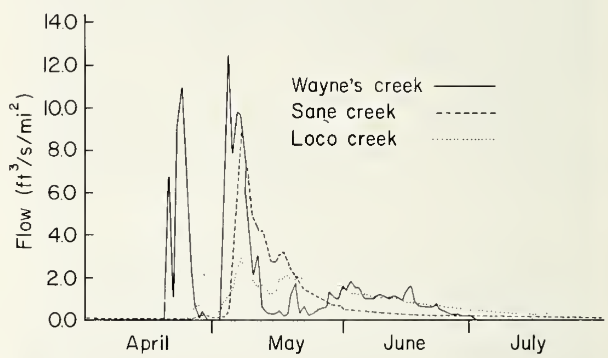

Figure 10.—Snowmelt runoff from sagebrush lands is sensitive to daily fluctuations in weather, as shown by flow on Wayne's Creek. Water flowing on top of the snow caused the high discharge rates on Sane Creek compared with those of Loco Creek, an adjacent watershed that did not develop over-the-snow flow.

Flow delivery on Sane Creek in 1970 (fig. 10) illustrates another hydrologic phenomenon, over-the-snow flow, that is probably best expressed in the sagebrush type. A well-developed drainage network on top of the snowpack in Sane Creek efficiently conveyed melt water from the watershed. The lower flow rate on Loco Creek is representative of the usual snowmelt runoff pattern. The channel eroded into the Sane Creek snowpack was about 6 feet deep and 3 feet wide (fig. 11). Discharge characteristics of Sane Creek were appreciably altered by the short-lived delivery system. Maximum instantaneous flow was more than three times as great as lfow in years without over-the-snow flow. Yield efficiency also exceeded that of Loco Creek for the only time on record because of the efficient drainage network provided by channels incised in the snowpack.

Over-the-snow flow develops when snowmelt on upland areas exceeds soil infiltration capacity. Water movement through the deep,

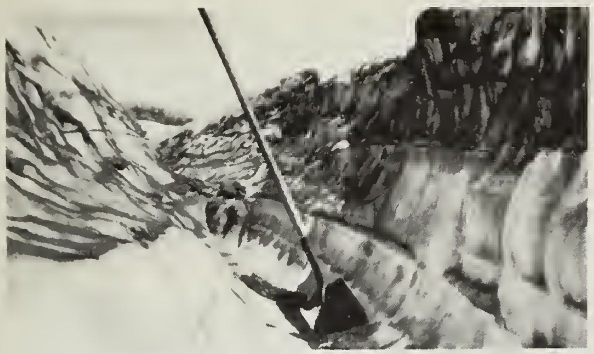

Figure 11.—Woter flowing over the snow surfoce from melt on uplond oreos produced this chonnel in the dense snow filling o droinogewoy. Such chonnels quickly convey melt woter from the wotershed with negligible tronsport losses. Dork moteriol on the sides ond bottom of the chonnel is soil deposited by runoff woter.

dense snow in channels is quite slow, and continued input causes the water to flow across the snow surface. The surface flow minimizes transport losses since little water infiltrates into the soil, but probably contributes to flooding that sometimes occurs from midwinter thaws on sagebrush land. Over-the-snow flow has been observed at the Wayne's Creek watersheds and at other locations in Wyoming as well. It is probably a common, but short-lived, phenomenon that develops to some degree every year wherever substantial quantities of snow accumulate in the sagebrush environment.

Summer Runoff from Rainfall

Runoff from summer rainfall is a function of the infiltration capacity of the soil, the amount and duration of rainfall, and rainfall intensity. Although instances of severe runoff and erosion resulting from convectional storms are evident throughout the sagebrush zone, detailed information about precipitation and runoff characteristics is limited for small watersheds. Thirteen years of study at Wayne's Creek suggests that most runoff events, in the higher parts of the sagebrush zone at least, are in response to rain falling on soil that is already wet, rather than in response to high-intensity storms. The majority of runoff events took place in June soon after snowmelt was completed or when soil was wet from previous rains; the runoff-producing storms were not particularly large or of high intensity (table 3). The highest runoff from rainfall equaled about 7 percent of precipitation. Instantaneous flow rates produced by rainfall were lower than those from snowmelt.

Table 3.--Characteristics of summer runoff events for a 13-year record period, 1959-71, in Wayne's Creek--a 60-acre high-elevation mountain sagebrush watershed in Wyoming

Date of events	Precipitation			Runoff	
	Amount	Intensity		Percent of precipitation	Maximum instantaneous flow
		Maximum	Average		
	Inches	*Inch/hr*			$ft^3/s/mi^2$
1962:					
June 22	0.26	3.60	0.08	0.5	0.3
1963:					
June 21	.12	.48	.07	1.5	.3
July 9	.50	--	--	.1	.5
1964:					
June 17	.39	1.80	.13	6.8	4.9
June 21	.20	.26	.06	.6	.4
1965:					
July 4	.10	1.50	.22	5.8	2.0
July 19	.35	2.70	.19	.1	.1
July 24	.72	1.88	.39	2.2	9.9
July 25	.16	.18	.04	.1	.4
July 25	.13	.60	.56	3.7	1.8
July 30	.44	.48	.17	.5	1.6
Aug. 19	.80	.36	.09	<.1	.2
Aug. 19	.41	.98	.18	1.3	3.1
Aug. 21	.31	.75	.14	.4	.7

HYDROLOGIC RESPONSE OF SAGEBRUSH LANDS TO MANAGEMENT PRACTICES

Vegetative Response to Sagebrush Conversion

An understanding of the hydrologic consequences of land management practices in the big sagebrush type requires a thorough knowledge of vegetative changes that accompany sagebrush removal. Past management practices have largely been oriented toward increasing the quantity of forage available to domestic livestock by killing sagebrush, thereby diverting site resources to herbaceous species.

Big Sagebrush

Removing sagebrush converts a shrub-dominated vegetation to one dominated by herbaceous species. As a practical matter, not all sagebrush plants are killed by any method of

conversion. Popular mechanical measures, except harrowing and railing, kill at least 90 percent of sagebrush plants when properly implemented (Pechanec and others 1965). Mechanical methods must be suited to the site and to the condition of the sagebrush stand. Kills approaching 100 percent are achieved by disking or plowing on rock-free sites where equipment can function properly. Carefully executed burns also kill most of the sagebrush plants. Spraying with 2,4-D in the spring when sagebrush is susceptible kills at least 90 percent of the plants. About 2 months is required for plants to completely defoliate.

Reseeding must be planned in conjunction with removal methods such as plowing and disking that destroy all vegetation. Failure to reseed permits sagebrush seedlings to establish, thus negating the control objectives. Planting is also necessary, whatever the control method, if there are inadequate numbers of valuable herbaceous plants to quickly occupy the site. Reseeding is recommended by Pechanec and others (1965) where desirable plants comprise less than 20 percent of total plant cover prior to treatment.

Crested wheatgrass *(Agropyron cristatum)* or Siberian wheatgrass *(A. sibericum)* have been the principal grasses planted on sagebrush lands. Rumsey (1971) found that production by introduced species exceeds that of undisturbed big sagebrush vegetation prior to conversion. Production by crested and Siberian wheatgrasses seeded in the 8- to 12-inch precipitation zone and a grass-alfalfa *(Medicago sativa)* mixture planted in the 12- to 16-inch precipitation zone was 46 percent and 124 percent greater, respectively, than herbaceous production by the climax big sagebrush stand.

Grass Production

Grass production commonly doubles after sagebrush removal. Burning, and methods other than plowing and disking, do not greatly alter herbaceous composition. Spraying strongly favors grasses over forbs, however. Early reports of chemical sagebrush control documented the increase in grass growth following treatment (Hull and others 1952, Hyder and Sneva 1956). Native grass production often doubles the year after sagebrush spraying and may further increase to triple that of unsprayed areas within 3 years. However, the increase to be expected over the long-term has not been adequately established. Certainly, subsequent grazing management is an important factor governing the length and magnitude of the response of grasses to sagebrush control. A typical response is shown in figure 12. Average production in the 6 years after treatment was 677 pounds per

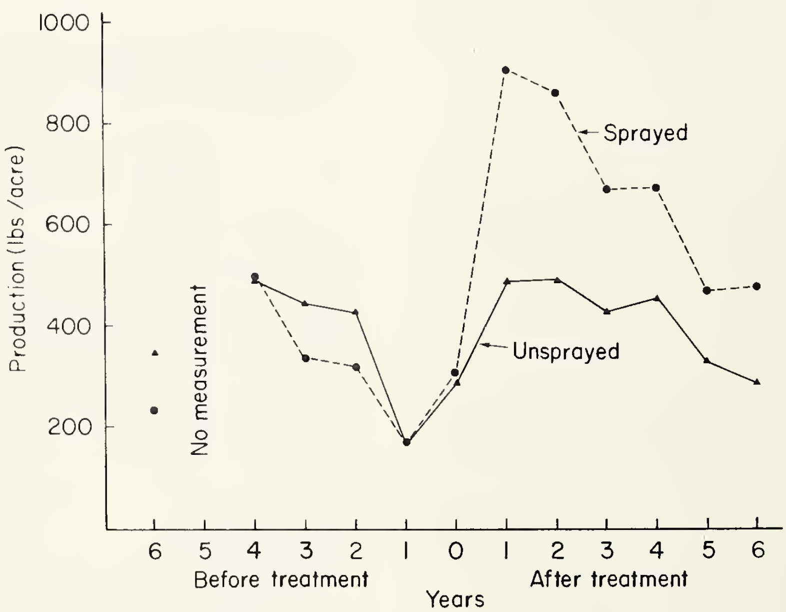

Figure 12.—Grass production (air-dry) for a sprayed and adjacent unsprayed high-elevation watershed.

acre (air-dry), about double the 312 pounds-per-acre average for 5 years preceding treatment. The watersheds were grazed moderately by cattle before spraying, but animals were excluded from both after treatment.

Forb Production

In climax big sagebrush stands, forbs can contribute from less than 20 to more than 50 percent of the herbaceous vegetation (Hyder and Sneva 1956, Tabler 1968, Smith 1969, Rumsey 1971). Of the sagebrush control methods that leave herbaceous vegetation relatively undisturbed, spraying is the only technique that drastically affects forb abundance. Phenoxy herbicides are not selective for sagebrush alone, but act against all broad-leaved plants. Spraying not only kills sagebrush, but severely curtails forb growth as well. The effect on a particular forb species depends on the growth stage of that species when spray is applied, whether it has food stored in roots, as well as its basic vulnerability to 2,4-D. The spray moderately or severely affected 13 of the 38 forbs evaluated by Blaisdell and Mueggler (1956).

Spraying a mountain big sagebrush watershed decreased forb production an average of 50 percent in the 6 years after treatment (fig. 13). Forbs recovered slowly. They contributed 37 to 45 percent of total herbaceous production in 5 years preceding treatment, but only about 15 percent the first 4 years after spraying. By the 6th year, forbs contributed 24 percent of total herbaceous production. Recovery can be faster than that indicated in figure 13. Thilenius and Brown (1974) found that grass dominance began to decline 2 years after spraying, and after 3 or 4 years the percentage composition of forbs had substantially recovered.

Forb damage is a little appreciated byproduct of spraying. The value of forbs as a forage resource for sheep and big-game is well known, but the dependency of other organisms on forbs is not fully appreciated. Forbs, for example, are an essential ingredient in the diet of young

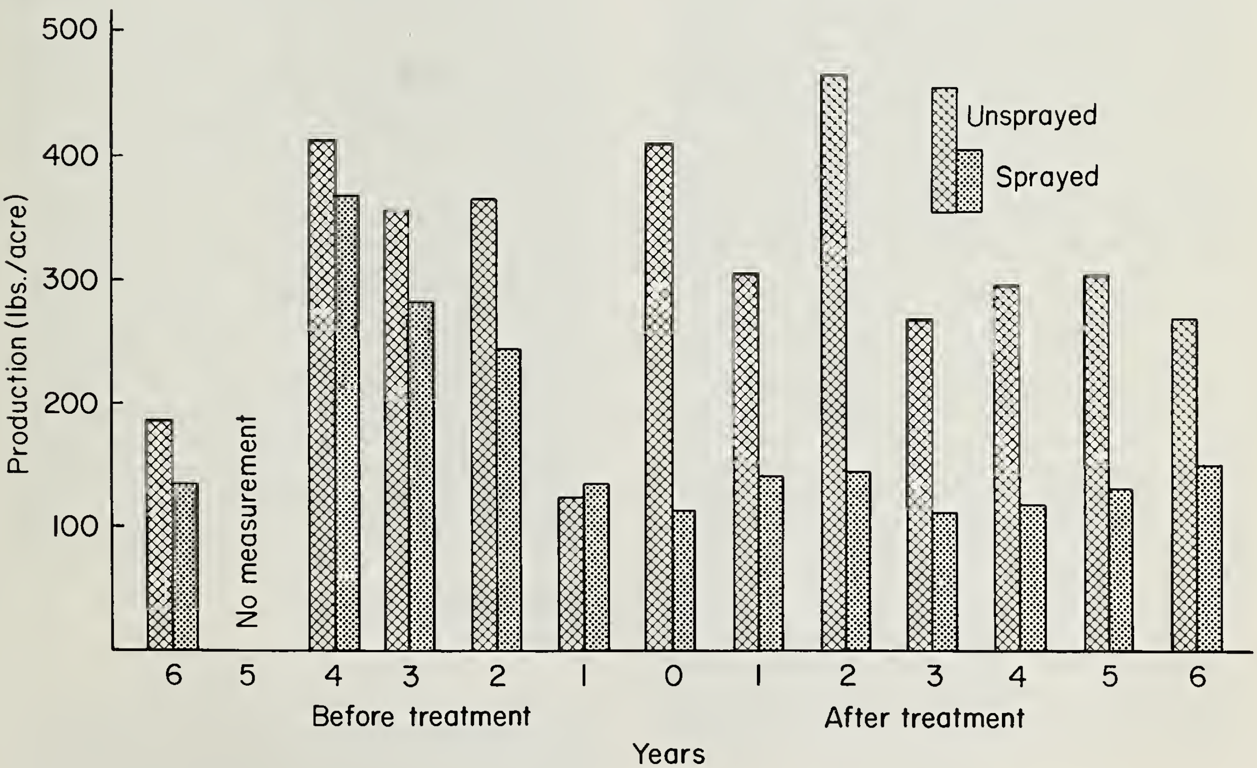

Figure 13.—Chemical herbicides used to kill sagebrush strongly reduce forb production as well. Forb production (air-dry) before and after spraying is shown on the same high-elevation watersheds as in figure 12.

sage grouse. Chicks consume forbs and insects about equally the first week of life, but for the next 9 weeks at least 70 percent of the diet is composed of forbs (Klebenow and Gray 1968). Cattle are thought of as grass consumers, but they seek out forbs as well, as shown by a study on sprayed range in the Bighorn Mountains. The contribution of forbs in the diet of yearling steers fell only from 42 to 33 percent, even though spraying reduced forbs from 80 to 10 percent of vegetation.[4]

Spray projects contemplated for sites with a productive forb component should be thoughtfully evaluated. Treatment shifts the forb-grass ratio to a strong grass dominance, but total herbaceous production does not respond proportionally to the increase in grass production. Sagebrush should not be sprayed where forbs are desirable from the standpoint of other land uses, and are still a productive part of the vegetative complex.

Combined Grass and Forb Production

The net effect of spraying depends upon the proportion of grasses and forbs in untreated vegetation. Where forbs comprise a substantial part of pretreatment vegetation, much of the increase in grass growth is offset by decreased forb production. For example, Tabler (1968) worked in an area where forbs contributed about 40 percent of the production total. After spraying, the loss of forbs was so great that combined grass-forb production did not equal that of unsprayed vegetation until the second year after treatment, when grass production had doubled. In contrast, if forbs contribute only a small part of the grass-forb total, the net effect of spraying more closely parallels the production response from grasses. Spraying had no effect on combined grass-forb production the year of treatment in a location where forbs contributed only about 15 percent of the production total before treatment (Sturges 1973). Combined grass-forb production was 1.8 and 2.1 times as great as for unsprayed vegetation the first and second years after treatment in this location.

A land manager can tailor plant composition to the projected resource use by reseeding after sagebrush removal. Palatable forbs and shrubs can be included in the seed mixture as well as grasses. These mixtures enhance seeded ranges from a wildlife point of view, and also provide valuable forage for domestic livestock.

Above-Ground Biomass Production

Sagebrush production is seldom, if ever, considered when evaluating the effect of sagebrush removal, since its herbage is considered of negligible value from a livestock standpoint except for sheep on winter range. Rumsey (1971) believes big sagebrush and three-tip sagebrush *(A. tripartita)* contribute no more than 35 percent of vegetative matter produced by climax big sagebrush vegetation in Idaho. However, sagebrush's contribution to total annual production is much higher than this on sites where sagebrush is to be removed as a range improvement practice. Big sagebrush contributed about 66 percent of total above-ground vegetation in south-central Wyoming (Sturges 1973), while Pechanec and others (1954) report sagebrush production in Idaho comprised 54 percent of the yearly total.

The production of above-ground biomass is reduced by sagebrush control practices, even though combined grass-forb productivity may substantially increase. Sturges (1973) attributed a 63 percent decrease in production of herbaceous biomass on a sprayed site the year of treatment solely to loss of sagebrush growth. Combined grass-forb production increased 79 percent the year after treatment, but the above-ground herbaceous biomass produced by sprayed vegetation was still about 30 percent less than that of unsprayed vegetation. Similarly, total production was 910 pounds per acre (air-dry) 4 years after burning in Idaho, but adjacent unburned range produced 1,080 pounds per acre (Pechanec and others 1954). The response of native vegetation to sagebrush conversion supports the ecological adage that a diverse mixture of species or classes of plants more fully utilizes site resources than does a single species or plant class.

Effective Life of Sagebrush Conversion

None of the methods used to kill big sagebrush permanently eradicates the brush. Not all plants are killed by treatment, and the remnants provide a seed source in addition to that already present in litter and soil, or carried onto a site by animals, birds, wind, and water. The rapidity of sagebrush invasion is a function of many things, but the degree of

[4]Unpublished material from John F. Thilenius, Plant Ecologist, Rocky Mountain Forest and Range Experiment Station, Laramie, Wyoming.

initial brushkill and subsequent grazing management are probably the most important. The importance of regulated grazing cannot be overemphasized.

Uncontrolled grazing of a burned Idaho range resulted in rapid brush invasion. The production by sagebrush reached pretreatment levels within 9 years under an unregulated seasonlong grazing regimen, but was less than 50 pounds per acre with proper grazing management (Pechanec and others 1954). Johnson (1969) also found unmanaged grazing accelerated invasion of sagebrush. On the other hand, the full benefits of sagebrush conversion are realized for a substantial number of years where conservative grazing practices are followed. Blaisdell (1953) found big sagebrush production was still at a low level 12 years after burning, but sometime in the next 18 years sagebrush attained preburn levels with a concomitant decline in production by grasses and forbs (Harniss and Murray 1973). Thilenius and Brown (1974) also noted sagebrush canopy cover was still substantially below pretreatment levels 12 years after spraying. In an Oregon study, the full benefit of spraying was present 17 years after treatment under a moderate grazing regime in which grazing was delayed until forage had matured (Sneva 1972).

Smith (1969) found moderate grazing the year of spraying did not increase sagebrush seedling establishment in comparison to grazing deferral for one, two, or three growing seasons after treatment.

Evidence now accumulating points toward an effective projected life between 15 and 30 years. Many crested wheatgrass plantings 20 to 30 years old are still productive in southern Idaho with little sagebrush invasion (Hull and Klomp 1966). Some stands, though, have required treatment to suppress the brush even where initial sagebrush kill was satisfactory and sound grazing management practices were observed. The 15- to 30-year projected lifespan is not well documented, particularly for spraying, since the majority of sprayed land was treated less than 15 years ago.

Ground-Cover Response

Factual descriptions of how ground cover responds to sagebrush removal are limited. The aerial canopy coverage provided by sagebrush is almost totally lost with treatment. Spraying a high-elevation, mountain sagebrush watershed increased litter cover slightly at the expense of rock and bare soil. However, the level of soil protection was high even before treatment due to a dense vegetative cover. Hyder and Sneva (1956) report the basal area of grasses increased about one-third after big sagebrush was controlled either by spraying or grubbing in an Oregon study. Most of the response was observed the year following treatment and was attributable to an increase in the number of grass plants as well as an increase in basal area of existing plants. Thus, the loss of sagebrush canopy is offset by increased basal area of herbaceous species. The resulting vegetative cover is more evenly dispersed than before treatment.

Soil-Moisture Response

Most information describing the soil-moisture regime under native and treated big sagebrush is derived from studies conducted in sprayed and unsprayed vegetation. These relationships still hold, however, for situations where a high level of sagebrush kill is achieved by other techniques.

The conversion of a mountain sagebrush stand to herbaceous vegetation reduced seasonal moisture withdrawal about 15 percent, and this difference develops while vegetation is actively growing (fig. 14). Moisture depletion is rapid when vegetation is actively growing, but sharply declines in midsummer. After midsummer the rate of moisture use is similar for both treated and untreated vegetation. The sharp decline in withdrawal coincides with the time herbaceous vegetation matures and the sagebrush drops many leaves.

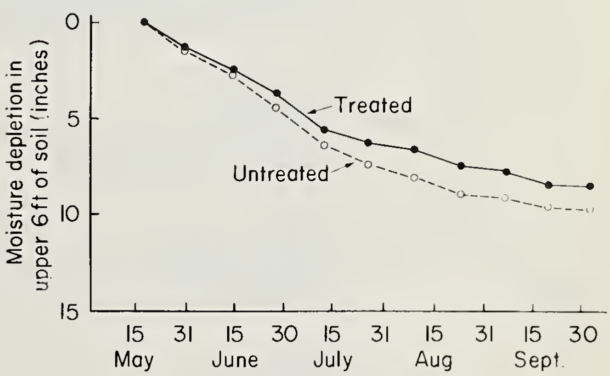

Figure 14.—Sagebrush conversion reduces summer moisture use about 15 percent. The reduction accrues during active vegetative growth, not uniformly through the summer season.

Most soil moisture is saved below the major rooting zone of residual vegetation (fig. 15). Native sagebrush utilizes moisture primarily from the upper 3 feet of soil until midsummer, then use shifts to the 3- to 6-foot depth. Most of the available water in the upper part of the soil has been utilized when deeper roots of sagebrush begin to actively extract water. About 80 percent of the reduction in withdrawal after sagebrush control, accrues in soil 3 to 6 feet deep. Moisture to support herbaceous species on treated land comes primarily from the upper part of the soil profile, and withdrawal there is about the same or exceeds that of undisturbed sagebrush (Hyder and Sneva 1956, Cook and Lewis 1963, Tabler 1968, Sturges 1973).

Some soil moisture is used by both sagebrush and replacement vegetation until late in the fall. However, once snow begins to accumulate, soil-moisture content remains static through the winter. This is not surprising in country where sagebrush is covered with snow and air temperatures seldom rise above freezing during the winter. In regions with a less rigorous winter climate, big sagebrush may continue to transpire in winter (Rickard 1967).

The reduction in soil-moisture depletion probably stabilizes at approximately 15 percent when replacement vegetation fully occupies the site (Tabler 1968), but can be substantially higher before vegetation fully responds to release from sagebrush competition (Shown and others 1972, Sturges 1973). To realize the savings, two conditions must be satisfied. First, soils have to be sufficiently deep that roots of replacement vegetation lie above soil occupied by sagebrush's deeper roots. Secondly, there must be sufficient precipitation to wet the soil throughout the profile. The method of killing sagebrush will not affect the magnitude of reduction as long as the rooting zone of herbaceous replacement vegetation is confined to the upper part of the soil and vegetation fully occupies the site.

Snow Accumulation

Snow relocation by winter winds is one of the more distinctive features of big sagebrush lands. Sagebrush leaves and twigs reduce wind velocity so that drifting snow is deposited and held in place. Live sagebrush plants and the

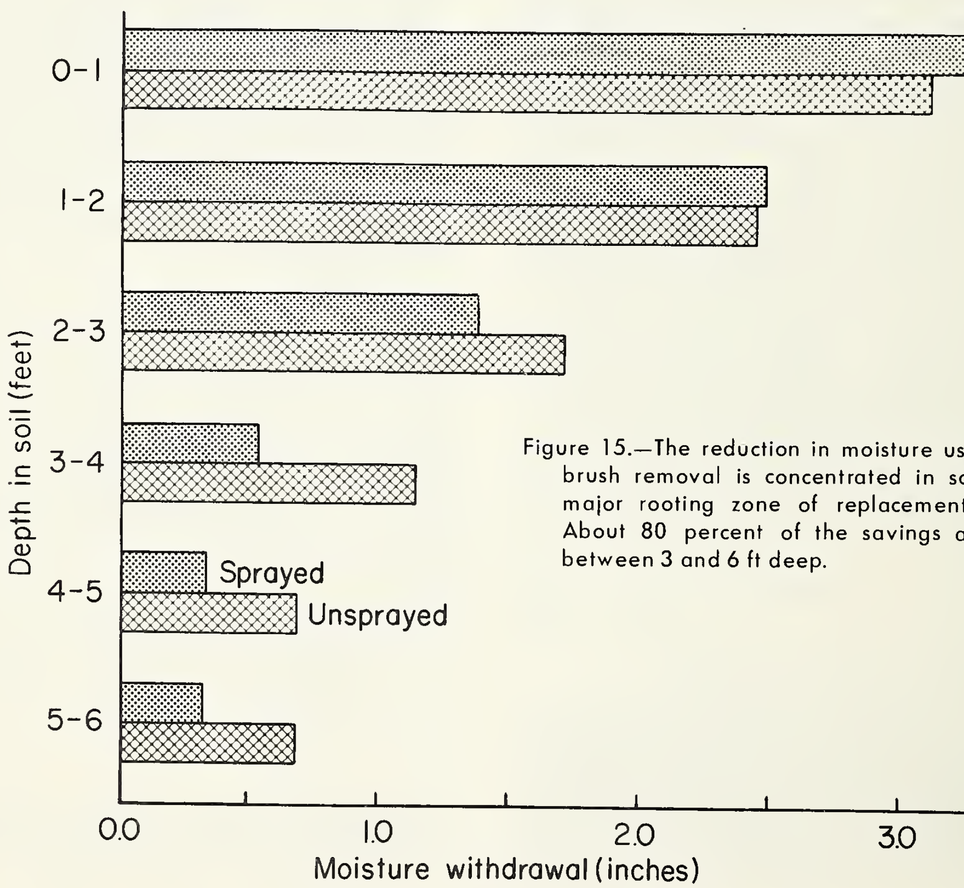

Figure 15.—The reduction in moisture use after sagebrush removal is concentrated in soil below the major rooting zone of replacement vegetation. About 80 percent of the savings accrue in soil between 3 and 6 ft deep.

skeletal remains of sprayed plants are more effective than herbaceous vegetation in retaining snow (Hyder and Sneva 1956). Snow accumulates faster in sagebrush cover than in grasslands as long as the brush remains above the snow surface. A stand of mountain sagebrush about 20 inches high contained an additional inch of water by the time the brush was covered compared with adjacent grassland (Hutchison (1965). The rate of snow buildup for the two cover types was the same after sagebrush plants were submerged within the pack, but the disparity in snow-water equivalent persisted through the accumulation period. Both vegetative types had a similar snowmelt rate, about 0.4 inch per day, during the period of rapid melt.

The relationship between sagebrush cover, aspect, prevailing wind direction, and snow accumulation is complex. Sagebrush conversion reduces snow accumulation most strongly on windward slopes, since the loss of sagebrush foliage opens the site to the scouring action of wind. Snowmelt and soil-moisture recharge may start earlier as a result of reduced snow accumulation (Tabler 1965). On leeward slopes, the effect of sagebrush removal is less pronounced. Here, removal may reduce the rate of accumulation early in the winter growing season while vegetation is uncovered, but have no effect on final depth if topography becomes the factor controlling snow deposition (fig. 16). Once vegetation is covered, further deposition becomes primarily a function of prevailing wind direction in combination with topographic location.

The above discussion treats snow accumulation at a particular point, not over an extensive area. Snow measurements on a sprayed and adjacent untreated watershed at Wayne's Creek

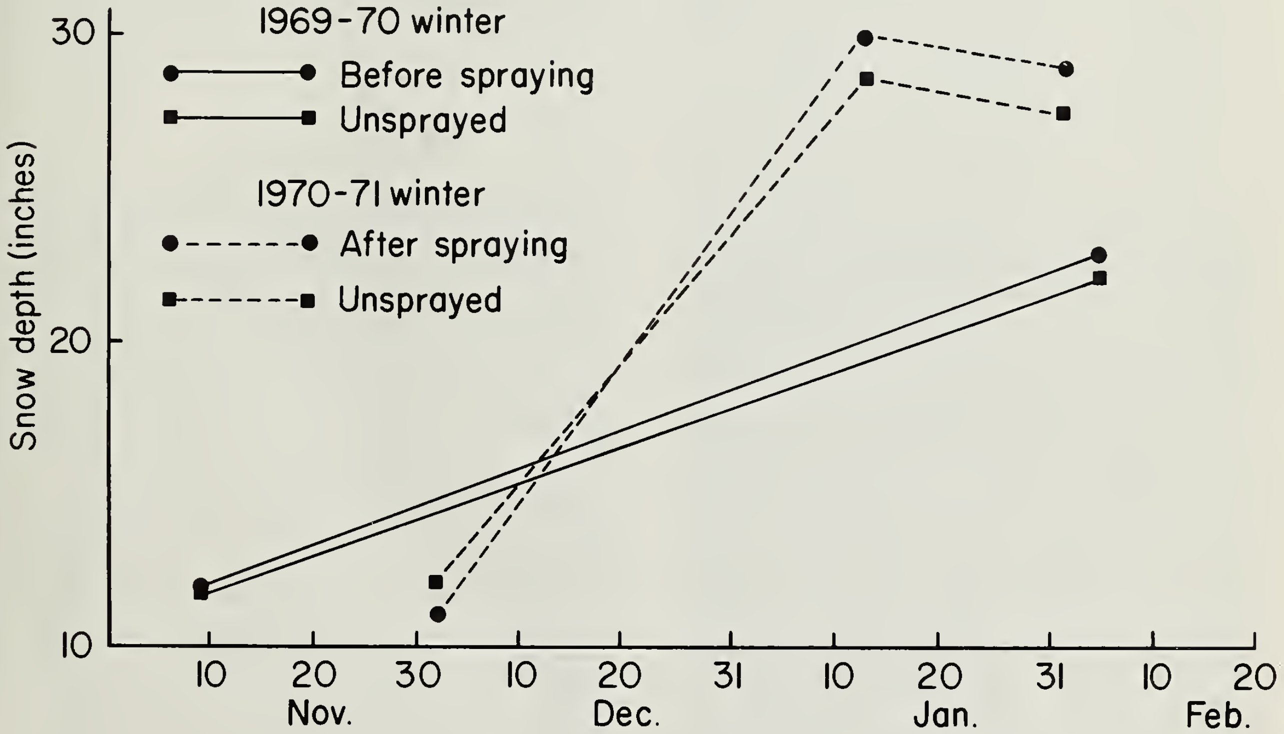

Figure 16.—Live sagebrush vegetation accumulates snow faster than herbaceous vegetation as long as sagebrush plants remain above the snow surface. In topographically controlled depositional areas, sagebrush removal may reduce accumulation early in the season but have no effect on maximum accumulation.

indicate sagebrush control did not affect snow storage. Watershed snow storage was dictated for the most part by topography, and ample snow-holding capacity existed in natural traps. Similar measurements to define the effects of sagebrush removal on snow accumulation over an extensive area at other locations have not been made.

Sediment Transport

Sedimentation rates from big sagebrush lands are not well known. Measurements of bedload and suspended sediment movement are being obtained on the Stratton Sagebrush Hydrology Study Area. Both types of sediment transport are low, and water flowing from watersheds is excellent in quality. The annual movement of bedload sediment at Loco and Sane Creek was recorded as follows:

Year	Loco Creek	Sane Creek
	(ft^3/mi^2)	
1970	355	179
1971	204	23
1972	168	8
1973	234	95
1974	121	14

The relationship between flow volume and suspended sediment concentration for Sane Creek (fig. 17) also indicates low suspended sediment movement. After snowmelt runoff, suspended sediment levels are usually less than 20 p/m (parts per million) on both Sane and Loco Creeks.

The high suspended sediment concentration associated with the May 20, 1973 runoff peak at Sane Creek (fig. 17) occurred during an over-the-snow flow event (see fig. 11). The flow rate at Sane Creek during 1974 was much lower than in 1973 and runoff water never did contain appreciable sediment. The deposition of bedload material at Sane Creek in 1970 and 1973 reflects an increase in sediment movement associated with an over-the-snow runoff event. Sane Creek's May 1973 peak streamflow rate and suspended sediment content emphasizes the importance of extreme events. Increased sediment movement can be expected in years with high snowmelt rates or with intense summer storms that produce overland flow, no matter how well the watershed is vegetated.

Sagebrush conversion techniques which minimize soil disturbance best maintain watershed protection values immediately after treatment. Gifford (1968) evaluated infiltration and erosion under simulated rainfall where sagebrush was killed by plowing, spraying, or ripping. He concluded that spraying was the best watershed rehabilitative treatment, and suggested plowing be used only where the likelihood of establishing a seeded stand quickly is high.

The only measurements relating sediment movement from an entire basin to sagebrush removal were conducted as part of the Wayne's Creek Study. Suspended sediment samples were collected at random intervals for 6 years preceding treatment and for 2 years afterward. Coarse sediment moving from watersheds was trapped in stilling ponds, and yearly deposition was measured in the fall. Suspended sediment

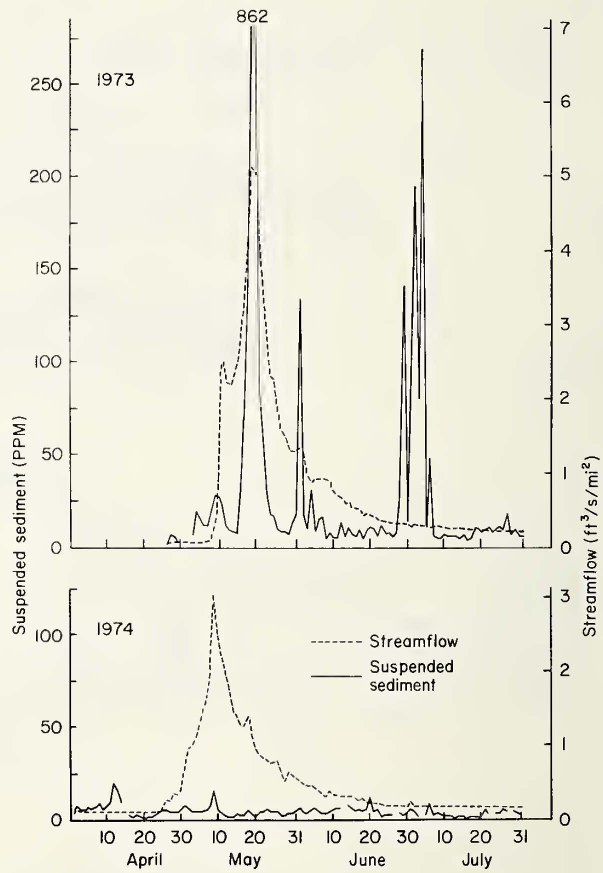

Figure 17.—Suspended sediment levels and flow volumes for Sane Creek during 1973 and 1974.

concentrations were consistently low, and averaged less than 30 p/m. The maximum concentration ever detected was 746 p/m and the minimum level was 1 p/m. No change in sediment load was observed after the brush was killed.

Coarse sediment transport was also small, as might be inferred from the small amount of suspended sediment present in stream water. Sediment deposition averaged between 4 and 5 pounds per acre per year. The greatest movement occurred in response to unusually high runoff. Coarse sediment movement was about three times the average yearly rate when winter precipitation was 53 percent above normal, again affirming the link between extreme events and accelerated rates of sediment transport. Suspended and coarse sediment measurements emphasize the importance of a vigorous vegetative cover in maintaining soil stability. The water coming from the watersheds was of excellent quality even during the height of runoff in most years. Sagebrush conversion further increased herbaceous production, which was reflected by an increase in litter cover and a decrease in bare soil and rock.

Streamflow Regime

Watershed streamflow measurements provide a means of assessing the net hydrologic effect of sagebrush control, since streamflow is the result of all hydrologic processes operating in a watershed. The relationship between sagebrush control and water yield has been studied at Wayne's Creek. Total annual flow was increased 13 percent by converting the shrub-dominated vegetation to a herbaceous type by spraying.

The increase in water yield closely approximates the difference in soil-moisture withdrawal between treated and untreated vegetation. Snow measurements indicated that water available for streamflow from snow was not altered by treatment. The increase in flow volume gradually accumulated through the snowmelt period because less melt water was required for moisture recharge. Treatment had no effect on the yearly maximum discharge rate, mean daily maximum discharge rates, or summer discharge during the low flow period.

Progress has been made in adapting a hydrologic simulation model developed by Leaf and Brink (1973) to model hydrologic processes operative in the big sagebrush type. Once this model is adapted, it will provide a useful tool for reliably predicting changes in water yield that will result when different range or watershed management practices are imposed on big sagebrush lands.

The 13 percent increase in streamflow is probably about the maximum that can be expected from sagebrush conversion at any location. Hill and Rice (1963) identified three essential conditions before conversion of chaparral shrub vegetation could influence water yields: (1) the rooting depth of shrubs must be deeper than 3 feet, (2) grass replacement vegetation must be kept free of deep-rooted species, and (3) precipitation must exceed the loss of soil water by evapotranspiration. These conditions were maximized at the Wayne's Creek site. The effect of sagebrush control on water yield at other sites will depend upon how well the three conditions are satisfied.

WATER-YIELD IMPROVEMENT IN THE SAGEBRUSH TYPE

Converting big sagebrush to a herbaceous vegetative type can probably increase water yield about 15 percent under the most favorable of circumstances. Because of low precipitation and shallow soils, conversion will not increase water yield on much of the land occupied by big sagebrush. Changes in the flow regime can be expected where precipitation is in excess of that required to replenish soil moisture, and where replacement vegetation utilizes less moisture than does native big sagebrush vegetation. The mountain big sagebrush type probably best fits these restrictions.

Recent research casts an entirely new light on water-management possibilities for big sagebrush lands, even on sites with relatively low precipitation and shallow soils. Wind is one of the paramount factors controlling snow accumulation. Not only is snow redistributed by wind, but vast quantities of water return directly to the atmosphere during drifting (Tabler 1973). Sublimated water is a total loss to the plant-land phase of the hydrologic cycle. Tabler (1971) has synthesized a means of estimating snow transport at a particular location, and based on this value, snowfence systems can be designed to capture drifting snow (Tabler 1972, 1973). Snowfences can be placed to provide water where there is none, much as trick-tanks do for rain, or they can be used to augment already existing sources. Thus, blowing snow ordinarily lost through sublimation during a drifting event can be trapped and the water diverted to meet a management objective.

The quantity of snow-water equivalent transported by wind is estimated by (Tabler 1971):

$$Q = \frac{1}{2}\, \Theta\, \bar{P}\, \bar{D}$$

where

Q = Annual volume of water-equivalent tha moves across a line 1 ft wide as drifting snow, in ft^3

Θ = Mean annual snow transfer coefficient, the ratio between the quantity of snow relocated by wind to that which falls during the winter drift period,

$\bar{P}$ = Mean winter precipitation received during the time snow is subject to drifting, in ft,

$\bar{D}$ = Average distance a snow particle travels before sublimating during the winter drift period, in ft.

This formula assumes that no barriers, other than natural vegetation, cause snow deposition in the area upwind of the measurement point, and that sublimation is proportional to the distance a snow particle travels.

Representative values of Θ and $\bar{D}$ were determined by Tabler (1972) from field measurements conducted in south-central Wyoming. The average winter snow transfer coefficient (Θ), was 0.7 for mountain big sagebrush stands 8 to 16 inches high. This coefficient indicates that 70 percent of the precipitation received during the time snow is subject to drifting returns directly to the atmosphere when no barriers cause deposition. The other 30 percent is stored in sagebrush crowns which protect the snowpack against the wind. Average annual values for $\bar{D}$ ranged from about 3,300 feet at a 7,500-foot elevation to 5,000 feet at an 8,500-foot elevation. The drift period extended from November 1 to March 30 at the Wyoming site, but can be adjusted to fit the climatic regime of any location.

The water equivalent of winter snow transport has been calculated for differing regimes of precipitation and maximum transport distances (table 4). Calculated values are astonishing, and suggest tremendously exciting management possibilities. These quantities are really "new" water completely outside the traditional resource base. Furthermore, the drifting-snow resource can be utilized with minimal impact on other land uses.

Snowfences properly located provide an efficient means to capture and retain windborne snow (fig. 18). A single fence traps about 80 percent of incoming snow between the time drifting starts and the fence is saturated.

Table 4.--Calculated quantity of water moving as drifting snow (per foot of width perpendicular to wind)for selected precipitation inputs and maximum transport distances, assuming a snow transfer coefficient of 0.7

Precipitation (Inches)	Water movement at maximum transport distances ($\bar{D}$) of -- 2,000 ft	3,000 ft	4,000 ft	5,000 ft
	- - - - - - - -	- - ft^3 - -	- - - - - -	- -
4	233	350	467	583
6	350	525	700	875
8	466	700	934	1,166
10	583	875	1,167	1,458
12	700	1,050	1,400	1,750

Preliminary measurements show that, at saturation on level terrain, standard snowfences used by the Wyoming Highway Department 6, 8, 10 and 12 feet high hold about 300, 500, 700, and 1,000 cubic feet of water per lineal foot of fence, respectively.

The following examples indicate the size of the drifting-snow resource. In an area where winter precipitation is 4 inches with a maximum transport distance of 3,000 feet, a snowfence would capture 280 of the 350 cubic feet of water transported across a line 1 foot wide. To accumulate 1 acre-foot of water requires a fence 6 feet tall and 156 feet long. The size of the drifting snow resource increases proportionally with greater precipitation and longer transport distances. If winter precipitation is 10 inches and the maximum transport distance 5,000 feet, two fences 38 feet long placed in tandem, one 10 feet high and the other 8 feet high, are necessary to hold the volume of drifted snow containing 1 acre-foot of water.

SUMMARY

Hydrologic Features of Mountain Big Sagebrush

Precipitation

Big sagebrush grows in an environment where the growing season is relatively warm and dry, and the bulk of yearly precipitation is received during the cold months. About 60 percent of annual precipitation falls as snow in

Figure 18.—Water that otherwise returns to the atmosphere during drifting can be trapped and stored behind snowfences, then used to meet a management objective. Blowing snow represents an extensive untapped water resource wherever snow is transported by wind

the mountain sagebrush zone. Summer precipitation is concentrated in June and September. Rain falling during July, August, and September contributes little toward vegetative growth. The amount of precipitation received in the summer is less than 0.21 inch on about 80 percent of days with precipitation, and in excess of 0.50 inch 6 percent of the time. Rainfall intensities in excess of 1 inch per hour generally last less than 10 minutes.

Wind and Drifting Snow

Wind is an important factor in the big sagebrush environment because of its role in redistributing snow. Windspeeds are highest during winter. A substantial part of winter precipitation returns directly to the atmosphere on lands where drifting is common. Snow is blown from windward slopes and ridges, and accumulates in topographically controlled depositional sites. Drifts, which may reach 10 to 20 feet deep, recharge ground water. Evaporation loss from late-lying snowfields and surrounding moistened soil is not known, but is probably an important constituent in the water balance of large drifts.

Water-Yield Characteristics

Streams originating in the mountain sagebrush zone yield a smaller percentage of precipitation as streamflow, and have a lower base flow and lower snowmelt discharge rate than forested subalpine watersheds. However, the form of the snowmelt hydrograph is similar for sagebrush and subalpine watersheds. The time required to accumulate a specified proportion of snowmelt runoff is similar when expressed as a percent of the runoff season. The timing of snowmelt, and discharge rates, are probably more variable in the sagebrush type than on forested land. Sagebrush lies at a lower elevation than timbered lands for the most part, snow depth is less, and snow is exposed directly to solar radiation.

Daily snowmelt flows in sagebrush country are extremely responsive to day-to-day fluctuations in weather partly because much of the snowpack is relatively shallow. Watersheds with a preponderance of south- and west-facing slopes are also subject to higher melt rates than watersheds where slope orientation minimizes solar energy input. Advected energy is probably an important source of energy for melting snow on sagebrush lands, because of persistent winds

and the relatively large portion of the watershed that becomes bare soon after melt begins. It is a particularly important component of the energy budget of late-lying snowdrifts. The proportion of energy contributed by advection to melt has not been measured, however, either on a watershed basis or for isolated snowdrifts.

Over-the-snow flow, one of the more unique hydrologic features of sagebrush lands, occurs when the melt rate on upland areas exceeds soil infiltration capacity and melt water accumulates in drainages. Runoff water can erode well-defined channels in the snow surface to form an efficient surface-drainage network that quickly transports melt water off the watershed. Over-the-snow flow is probably a common but short-lived phenomenon wherever sagebrush lands accumulate substantial quantities of snow. Sediment movement is accelerated during over-the-snow flow events.

Runoff from summer rainstorms on high-elevation, mountain sagebrush watersheds is generally the result of rain falling on premoistened soil; storm intensity need not be high. Most surface runoff events occur soon after snowmelt or are associated with rainy periods. Wet soil has a lower initial infiltration capacity than dry, and a constant infiltration rate is reached sooner. Summer runoff rates are generally substantially lower than maximum discharge rates during snowmelt.

Hydrologic Response of Big Sagebrush Lands to Management Practices

Vegetative Response to Sagebrush Conversion

Big Sagebrush.—More than 90 percent of big sagebrush plants are killed by burning, mechanical removal techniques, or chemical herbicides, when control measures are properly implemented. The use of 2,4-D revolutionized range management practices on sagebrush lands. Reseeding must accompany sagebrush conversion on sites where all vegetation is destroyed, or the population of desirable species is low. Reseeding presents an opportunity to establish the kinds of plants suited to a particular management objective.

Grass production.—Burning, and mechanical methods that do not destroy herbaceous vegetation, do not greatly alter herbaceous composition. Spraying, however, strongly favors grasses over forbs. Grass production commonly doubles after spraying. Subsequent grazing management is an important factor governing how long the production response by grasses persists after treatment.

Forb production.—Spraying is the only sagebrush control method that drastically affects forb abundance. Phenoxy herbicides act against all broad-leaved plants, not just sagebrush. The effect on individual forb species depends on the time of spray application in relation to growth stage, and the amount of root reserves. Spraying reduces forb production approximately 45 to 65 percent. Forb damage should be carefully considered when assessing the suitability of a particular site for spraying, since forbs are essential to some land uses.

Above-ground biomass production.—The production of above-ground herbaceous biomass (including production by sagebrush) is reduced by sagebrush removal. Native grasses and forbs do not increase sufficiently to replace herbage produced by sagebrush. Combined grass-forb production can increase approximately 50 to 200 percent after sagebrush control. The increase in grass production alone is not a valid measure of treatment effect when sagebrush is sprayed. Forbs as well as sagebrush are killed, so that part of the grass response simply compensates for decreased forb growth. There is some indication that production by introduced forage species may exceed that of climax big sagebrush vegetation.

Effective life of sagebrush conversion.—No control method eradicates big sagebrush; periodic recontrol is necessary to hold it in a subordinate position. The degree of initial sagebrush kill and grazing management are the most important factors controlling the rapidity of brush invasion. The effective projected life is probably 15 to 30 years, but this timespan has not been conclusively established.

Ground-Cover Response

Quantitative data describing the response of ground cover to sagebrush removal are limited. Litter cover increased slightly, while rock and bare soil decreased after spraying on a high-elevation watershed. More than 80 percent of the watershed surface was protected by vegetation or litter before treatment. The basal ground cover of bunchgrasses increased by a third following sagebrush control in a study located within the drier part of the sagebrush zone. Individual grass plants respond to release from sagebrush competition with an increase in overall vigor, including an expanded basal area.

Soil-Moisture Response

Summer soil-moisture withdrawal decreases about 15 percent after sagebrush removal if (1) the roots of residual vegetation are above soil previously occupied by the deeper roots of sagebrush, and (2) precipitation is sufficient to wet the entire soil mantle. The reduction accrues in soil below 2 feet while vegetation is actively growing. Moisture depletion in the top 2 feet of soil is the same or slightly greater since the zone of major root activity is shifted to the upper part of the soil profile.

Snow Accumulation

Snow relocation is an important hydrologic feature of big sagebrush lands. Vegetation, and wind in combination with topography, are the dominant factors controlling snow deposition. Live sagebrush plants collect snow more efficiently than herbaceous vegetation or dead sagebrush skeletons. Sagebrush removal can reduce snow accumulation or windward slopes. However, overall snow storage was not affected by sagebrush removal in a small basin with ample snow storage capacity where topography and wind were the primary factors controlling accumulation.

Sediment Transport

Techniques that minimize soil disturbance are best for converting big sagebrush vegetation to a herbaceous vegetative type. Plowing should be restricted to lands with little erosion potential where a seeded stand can be established quickly. Sediment transport from a high-elevation watershed with a small amount of bare soil before treatment was unaffected by sagebrush conversion. How sagebrush removal affects soil stability at sites with lower initial soil protection has not been determined.

Streamflow Regime

Changes in streamflow regime provide a measure of the net hydrologic effect of sagebrush control. Total annual flow increased 13 percent after mountain big sagebrush was sprayed on a high-elevation watershed. Treatment did not affect maximum discharge rates during snowmelt or flow volume after the snowmelt period. The maximum potential increase in streamflow from sagebrush control at any location is probably about 15 percent.

Water-Yield Improvement in the Sagebrush Type

The maximum increase in water yield that can be realized by conversion of big sagebrush to a herbaceous type is probably about 15 percent. Brush removal will not affect water yield where soils are shallow and precipitation is insufficient to rewet the soil.

Snow currently lost to sublimation represents an untapped water resource on sagebrush lands wherever snow is drifted by wind. Vast quantities of water return directly to the atmosphere during drifting; sublimation from wind-transported snow equaled 70 percent of winter precipitation at a site in south-central Wyoming. Snowfences provide an efficient means of capturing drifting snow, and have little impact on other land uses. When saturated, fences 6, 8, 10, and 12 feet tall located on level terrain hold about 300, 500, 700, and 1,000 cubic feet of water per lineal foot of fence, respectively. Fences can be effective in lower precipitation regions of the sagebrush type as well as regions of higher precipitation, as long as winds are sufficient to induce drifting. Direct sublimation of snow and evaporation of melt water may also account for a substantial portion of water stored in isolated drifts behind snowfences, however.

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Although this report discusses research involving pesticides, such research does not imply that the pesticide has been registered or recommended for the use studied. Registration is necessary before any pesticide can be recommended. If not handled or applied properly, pesticides can be injurious to humans, domestic animals, desirable plants, fish, and wildlife. Always read and follow the directions on the pesticide container.

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Agriculture—CSU, Ft. Collins

Sturges, David L.
1975. Hydrologic relations on undisturbed and converted big sagebrush lands: The status of our knowledge. USDA For. Serv. Res. Pap. RM-140, 23 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521

The status of our knowledge of watershed management for big sagebrush range lands is discussed. Climate, soils, vegetation, snow accumulation, and water yields are described, followed by a review and discussion of how management practices alter vegetative composition and the hydrologic regime. Potential hydrologic benefits from managing blowing snow in the big sagebrush type are outlined and research needs are highlighted.

Keywords: Multiple use, range hydrology, vegetation effects, watershed management, blowing snow management, *Artemisia tridentata*.

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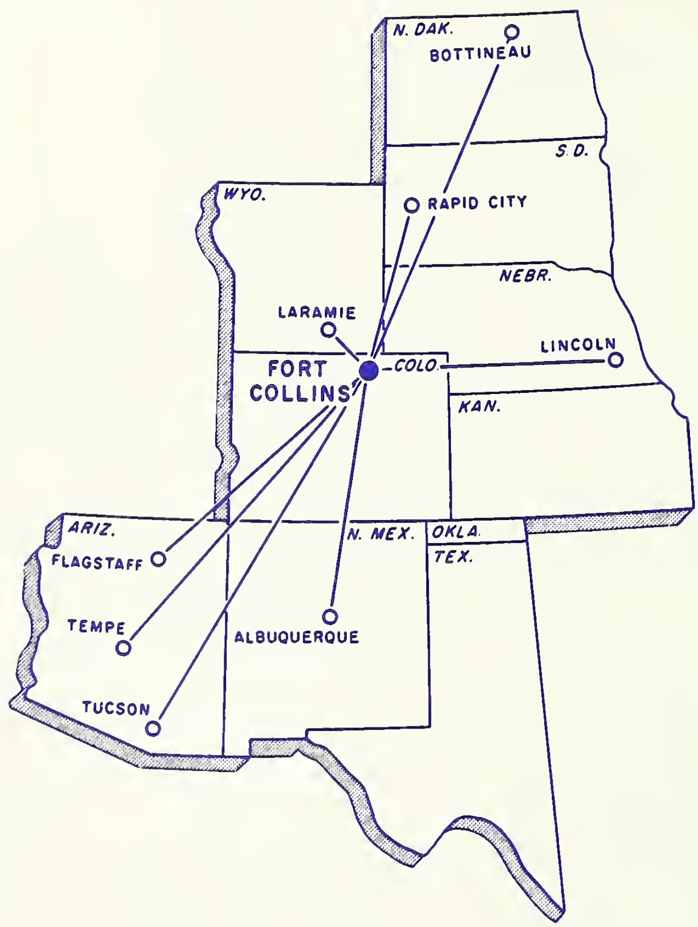
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